CURFMAN

Investigation
Of Sand - Lime Brick

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INVESTIGATION

OF

SAND-LIME BRICK

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

LAWRENCE EVERETT CURFMAN

ENTITLED INVESTIGATION OF SAND-LIME BRICK

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering

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INVESTIGATION OF SAND-LIME BRICK.

I. INTRODUCTION.

In this age of progress new materials of construction are constantly being brought to the attention of the engineer and the architect. Many of these materials are manufactured by patented processes. Some of them prove very valuable, becoming almost indispensible; while others are worthless, or differ from something already in use just enough to enable the inventor to secure a patent. However, the human race has profited so much by inventions of real value, that no invention should be passed by without due investigation.

One of the materials rapidly coming into use is sand-lime brick. This is an artificial stone made in the form of a brick, or block, from sand and lime. A mixture of sand and lime used as a mortar was one of the first building materials; but it was not until the last century that sand and lime were moulded into blocks.

The first experiments in making bricks from sand and lime appear to have been undertaken at Potsdam, about thirty years ago. They were suggested by the fact that Potsdam, like many other places in central Germany, is surrounded by a wide, sandy plain, which furnishes neither clay for bricks nor stone for building purposes. These sand-lime bricks were first hardened by exposure to the air, a tedious process which required several months, although the bricks hardened in that way have stood all tests and continue to harden with increasing age. Fig. I. shows an old house built of sand-lime brick hardened in this way.

About 1880 the discovery was made that freshly pressed bricks of

sand and lime could be hardened in a few hours by heat and pressure of steam. During that year a patent was granted by the German Government to Dr. Wm. Michaelis, a noted cement engineer, of Berlin on the hardening of sand-lime brick in a cylinder under heavy steam pressure; but owing to the impossibility at that time of obtaining cylinders capable of withstanding this heavy steam pressure, and presses strong enough for the work, this patent was allowed to expire without any commercial use being made of it.

OLD SAND=LIME BRICK HOUSE, BUILT BEFORE 1860.

Located at 907 Government Street, Mobile, Alabama. This house was built some time in the fifties, by a man named Sadler. The brick were made by hand and air-hardened, the process taking several months. They are not so perfect in form and finish as our modern brick, but the building is in fine condition. A number of these old buildings are to be found in various parts of the country.
From a Photograph

Fig. 1.

All the modern systems of sand-lime brick-making are based on this expired patent; therefore the manufacture of such brick is as free

to all as the making of clay brick. No patents on the process exist, and none can be obtained, at least in this country. The difference between the various systems in use consists mainly in the methods of mixing, handling, and preparing the materials, especially the lime,-and in the types of machinery used.

Several systems have been in use in Europe for eight or ten years, and a large number of plants have been established in this country within the last four or five years under various systems, most of which are working successfully in a commercial way. Some of these plants are of course more successful commercially than others; this is the case in all industries, and depends on local conditions, the quality of materials used, and the business management of the plant, and largely on the machinery and system adopted. In 1896 Germany had only five factories where sand-lime bricks were made, but now it has about 200, with an actual annual output of between 350,000,000 and 400,000,000. The first reported plant in this country was built at Michigan City, Ind., early in 1901. In 1902 about 20 plants were in existence and 6,000,000 bricks were actually sold. Full and accurate data are not obtainable as to the actual output in 1903, but about 20,000,000 bricks have been reported as sold in that year. The number of plants is increasing very rapidly. When the writer began to collect material for the tests (June, 1904), he was unable to find a sand-lime brick plant in Illinois. Now there are at least three plants in Illinois, and there are rumors of several others in progress or contemplated. The three contemplated are at Kankakee, Peoria, and Wilmington.

Sand-lime bricks have been hardened in several ways; viz., in

the open air, in an atmosphere of CO_2 by steam under pressure, and by a combination of the last two. It seems, however, that the hardening by steam under pressure is the only method of commercial importance, and only brick of this kind will be considered in the following investigation.

II. THE PROCESS.

This discussion will be limited to bricks composed of lime and sand bound together into an artificial stone by a cementing material which consists largely of calcium or magnesium silicate. The quality of the product depends on four things; (1) the materials, (2) their preparation, (3) the moulding, and (4) the hardening, which will now be discussed briefly.*

Almost any sand can be used, and a fair product made, if the treatment of the sand is properly varied to suit its physical and chemical properties. Economy in manufacture, however, limits both the physical and chemical properties.

For mortar it is customary to specify "clean, sharp, course sand". Should the sand for sand-lime brick also have these qualities? Mr. Peppel has made elaborate experiments to determine the effect of various impurities, and of the size of the sand grains. He made cubes and briquette, using mixtures of coarse and fine sand in different proportions, treating them otherwise as nearly as possible the same.

*The material for this discussion was obtained from an article in Vol.V of the Transactions of the American Ceramic Society entitled "Further Contributions to the Manufacture of Artificial Sandstone or Sand Brick", by Mr. S. V. Peppel.

The results seem to indicate that the crushing strength increases when the amount of course sand increases, but the tensile strength diminishes under these conditions. Of course this is true only within certain limits which have not yet been determined.

The impurities most commonly found in sand are clay, mica, feldspar, and usually some ferric oxide. In order to determine the effect of clay Mr. Peppel prepared cubes and briquette using different proportions of kaolin. The results show that the crushing strength grows smaller with the addition of the kaolin; and that the tensile strength sometimes grows smaller and sometimes larger, depending on other conditions. Experiments were also made to determine the effect of feldspar. The results show a decrease in crushing strength and an increase in tensile strength with the addition of feldspar.

Mr. Peppel believes that sharp sand is better than smooth, but he made no experiments along this line.

b. The Lime.

The quanity of lime commonly used by manufacturers varies from five to ten per cent. Mr. Peppel studied the question and used different quanities of lime up to 40 per cent as much lime as sand. His results show that the crushing strength increases when the per cent of lime increases, but not proportionally.

There are two different kinds of lime on the market -- gray and white. The gray lime is a high calcium lime; while the white lime contains both calcium and magnesium - usually in the ratio of about 5 to 4. The latter is called dolomitic lime. Mr. Peppel made some tests using the same proportions of the two kinds of lime in differ-

ent specimens, and found that those made from the high calcium lime were about one third stronger in compression and tension and had a smaller absorption than those made from dolomitic lime.

2. Preparation of Materials.

The preparation of the materials varies greatly with the quality and condition of the sand. If the source of supply of the sand is a soft sandstone, the latter may have to be broken up by means of some kind of crusher. Unless some of the sand is very fine, a small portion of it should be pulverized. Again, if the sand is obtained by dredging, it will probably be too wet to be used by any of the processes, and must be dried at least partially. The sand may be dirty, as from a river bed, or may be covered with salt, as sand from the sea-shore, in which case it should be washed.

In the preparation of the lime lies the main difference between the patent processes or systems in use. Briefly, the processes are: (1) the wet slaking ; (2) dry slaking ; (3) steam slaking ; (4) acid slaking ; and (5) the quick-lime, or oxide process. In the first process the lime is slaked to a fat putty, then mixed with the desired proportion of sand and water, allowed to stand a little while to ripen, and finally it is pressed. In the second process enough water is added to complete the slaking, with a very little excess, which is driven off by the heat generated in slaking. In the third method the lime is slaked by steam, either before or after it is mixed with the sand. In the fourth process from five to ten per cent of a solution of commercial hydrochloric acid is added after the slaking has begun. In the fifth process the quick lime is reduced to a powder, and then mixed with the sand. The water is added

in two portions with a short interval of time between.

By the first method thorough and rapid hydration is obtained, but it requires more mixing to acquire a uniform mixture with the sand. By the second process thorough hydration is obtained with difficulty, if ever at all. The steam slaking produces thorough hydration and a dry hydrate, but the process is slow. The addition of hydrochloric acid is of doubtful utility, for $CaCl_2$, if it remains in the brick as such, is soluble in water, and would be injurious. If the $CaCl_2$ is decomposed according to the formula,

$$CaCl_2 + SiO_2 + H_2O = CaSiO_3 + 2HCl,$$

the acid thus liberated would be very injurious to the metal of the hardening cylinder. If the dry, ground quick-lime is used, the mixing is much easier; but unless the lime is thoroughly hydrated, there is danger that further hydration will take place in the hardening cylinder, causing the lime to expand and injure the brick seriously. By proper attention to the difficulties attending it, any of the above processes, except the acid slaking, may be used with good results.

The mixing of the sand and lime is done by machinery--edge-runners, wet and dry pans, and various machines of the pug-mill type being used.

3. Moulding.

The quality of the product depends upon the moulding. Mr. Peppel made some experiments to determine the best moulding pressure. He prepared four different mixtures and from these made blocks, using moulding pressures of 5,000, 10,000, 15,000, and 20,000 pounds per square inch. The results show that the pressure

which gave a maximum crushing strength for all the mixtures was about 15,000 pounds per square inch. The crushing strength for the blocks made at this pressure was about twice that of those made from the same mixture at a pressure of 5,000 pounds per square inch.

4. Hardening.

The quality of the product depends upon the steam pressure and upon the length of time of exposure. Mr. Peppel has studied both of these questions and his results show that a high pressure developes the full strength of the brick in a few hours - 3 or 4 - and the lower the steam pressure the longer the exposure required. The blocks for these experiments were moulded under a pressure of 15,000 pounds per square inch. When a steam pressure of 150 pounds was used, 4 hour's exposure was sufficient; for a pressure of 120 pounds, 6 to 8 hours were required, and for a pressure of 100 pounds, 8 to 12 hours.

III. THE PRODUCT.

We come now to the primary object of this investigation. We wish to determine whether the sand-lime brick now being made are fit for use under all conditions where clay building brick are now used.

The makers of sand lime brick claim for their product that the brick are equal in appearance and quality to any dry--pressed or re-pressed front brick; further, that they gain in hardness under the action of air and water. They also claim that they may be used as fire brick. The writer has investigated each of these claims. The discussion will be taken up in the following order; (1) Appearance; (2). Uniformiy of size, shape, color and structure; (3) Strength;

and (4) Durability.

1. Appearance.

Whether the brick are pleasing in appearance or not, is, of course, largely a matter of taste. If properly handled they have very smooth surfaces and sharp edges. The color of the ordinary sand-lime brick is a grayish white - see Fig. 2. But, for a slight additional cost, they may be made almost any color by the introduction of coloring matter into the mixture composing the brick. See Plate 1. on the following page.

Fig. 2.- Sand-Lime Brick.

2. Uniformity.

The brick are very uniform in every way. They are uniform when they come from the press and there is nothing in the hardening process to distort them. The edges, or two-inch faces, of the brick are especially straight and smooth, and free from the kiln marks frequently found even on the best of clay brick. In a general way

Plate I. - Colored Sand-Lime Brick.

these facts are shown by a study of Fig. 2. In color there is much less difference than is usually found in clay brick. In structure they are extremely uniform. This was shown by the failures in the transverse and crushing tests, to be referred to later.

3. Strength.

The sand-lime brick are not so strong as the average clay building brick, but they seem to be sufficiently strong for all purposes for which the ordinary building brick are used. Two tests were made; viz., the transverse or beam test, and the crushing test.

Transverse Test. The transverse test was made by placing the brick on edge on two supports six inches apart, and applying a load at the centre. The supports and center piece were wedge-shaped, curved slightly longitudinally, and had the edges rounded to a radius of about $\frac{1}{4}$ inch. Since the supports were thus rounded, it was not thought necessary to use any means of distributing the pressure further. However, one or two of the brick failed by shear over one of the supports. The failures were nearly all square across the brick at the centre and showed a uniform structure. The modulus of rupture was calculated by the formula $\frac{9W}{bd^2}$, where W is the load at the centre in pounds, and b and d are the breadth and depth of the brick respectively in inches. The results are given in Table I, with two results for clay brick for comparison.

Table I.

Transverse Strength.

Ref. No.	Private Mark.	Kind of brick.	Modulus of Rupture 1 lb. per. sq. in.	Number Tested	Result by
1	C.	Sand-Lime	509	15	Curfman.
2	C. S.	"	766	3	" "
3	U.	"	420	10	" "
4	S.	"	607	22	" "
5	T.	"	555	5	" "
6		"	635	1	See note 1.
7		Clay	1721	9	Curfman
8		"	800		See note 2.

Note 1. Result by Iowa State College..
Note 2. "Treatise on Masonry Construction," by Prof. I. O. Baker.

Compression Test. In the compression tests half brick were used flat. They were bedded in plaster of paris, which was allowed to set in the machine under a pressure of about 300 pounds per sq. inch, so that it was well forced into the irregularities of the brick. When the plaster of paris had set the brick were crushed without disturbing their position in the machine. At the beginning of the investigation it was discovered that the brick were affected by being wet. For this reason paper was placed between the brick and the plaster of paris to protect the brick somewhat from the water in the plaster of paris. The results of the tests are given in Table II.

Durability.

The durability of the brick seems to be the most important. No matter how strong, or how pleasing to the eye a brick is, it will not be used if it is known that it is not durable. The ele-

Table II.

		Crushing Strength.			
Ref. No.	Private Mark	Kind of Brick	Average Ultimate Strength, lb. per sq.in.	Number Tested	Result by
1	C.	Sand-lime	4344	12	Curfman
2	C.S.	" "	6123	3	"
3	U.	" "	2412	12	"
4	S.	" "	2244	13	"
5	T.	" "	3340	5	"
6		" "	7300		See Note 1
7		" "	952	15 cubes	" " 2
8		" "	2943	10	" " 3
9		" "	4470	1	" " 4
10		" "	3002	2	" " 5
11		" "	3147	1	" " 6
12		" "	3846	3	" " 7
13		Clay	5690		Baker

1. Result from Colorado School of Mines, in "The Clay-Worker", Jan., 1905.
2. Result by Mr. H. B. Fox, of the University of Illinois, in "Clay Record", Jan. 16, 1905, p. 35.
3. Columbia University, in advertising literature of brick company.
4. Purdue University, in advertising literature of brick company.
5. Mc Gill University, in advertising literature of brick company.
6. Pratt Institute, in advertising literature of brick company.
7. Pittsburg Testing Labratory, in advertising literature of brick company.

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ments which may affect the durability of a brick in the wall are:- wind, water, frost, and occasionally fire.

Effect of the Atmosphere. A test to determine the effect of the wind, or air, was not thought of at first; but some results, which were obtained in some of the other tests, seemed to be due to some kind of ripening or hardening process effected by the air in the presence of moisture. These results were obtained in some experiments where, in order to hasten the drying of some brick which

had been thoroughly soaked, they were placed on a hot steam radiator. While in this position they were continually warm and surrounded by a current of warm air. After remaining here for three days they were crushed, as were also the other halves of the same brick, which had remained dry all the time. The first time this was done the average crushing strength for the three re-dried halves was 108 per cent of the average for the three other halves. The writer at first supposed this to be due to some inaccuracy in results or method; but in a second test under about the same conditions, the average for five re-dried halves was 110 per cent of the other halves in their original condition. These results led to a test which was intended to show whether or not air in the presence of moisture affects the brick. Five brick were broken in halves and one set of halves were kept in their original dry state. The other set were soaked in water and piled on a hot steam pipe where there was a current of air constantly rising. These halves remained here seven days, and for the first five days they were immersed in water for a few moments twice each day. Both sets of halves were then crushed. The strength of the ripened halves, expressed in per cent of the original halves, were 95, 90, 108, 109, and 110 per cent. The last three of these results agree very closely with those mentioned above, but the writer does not consider the test conclusive proof that air and water harden the brick.

Effect of Water. The question arises whether brick used in damp places are affected by the moisture, To determine if the water has any effect on the strength of the brick, one half of a brick was soaked thorougnly - never less than 48 hours - and crushed.

The other half was crushed dry. In Table III is found a comparison of the results.

Table III.

Effect of Water on Crushing Strength of Sand-lime Brick.

Ref. No.	Private Mark	Average Crushing Strength. (lb.per sq.in.)		Strength Wet in per cent of Strength Dry.	Number Tested	Authority
		Dry	Wet			
1	C.	4292	2882	66	6	Curfman
2	C.S.	5970	4560	76	1	"
3	U.	2405	1475	61	6	"
4	S.	2122	1690	80	5	"
5		2207	2218	100	5	See 1.
6		1548	1321	85	10	" 2.
7		1108	908	77	10	" 2.

1. Thon Industrie Zeitung, Vol. 25, p. 575.
2. " " " " " " 1660

Effect of Frost. In a climate such as that of Illinois, where the changes in the weather are frequent and great, the determination of the effect of frost becomes of the greatest importance. Let us see what are the conditions under which frost, or cold, can affect the brick. Of course a perfectly dry brick cannot be affected by frost for there is nothing in it to freeze. But when a damp brick is exposed to cold, the water in it freezes, and in freezing expands and breaks the bond uniting the particles. The amount of injury to the brick depends on the amount of this expansion. The amount of expansion depends upon the amount of water in the brick, and upon the thoroughness of the freezing. The thoroughness of the freezing depends upon the length of time of exposure to the cold, or upon the degree of coldness. Arguing thus we would expect the effect of

freezing to be greater the greater the amount of moisture contained in the brick, the lower the temperature, or the longer the brick is exposed to this temperature until the freezing is complete.

Absorption. - As stated above, the injury due to freezing depends upon the amount of water which the brick contains. The amount of water which the brick can contain is indicated by the absorption. The test for absorption is probably the one most frequently made on brick, perhaps, because it is most easily made and requires the least apparatus. It seems to the writer that this test is the most important of all in the case of sand-lime brick, because it is an almost certain indication of the results of most of the other tests, as will be seen from a comparison of the tables. By absorption is usually meant the amount of water which a brick will absorb, expressed in per cent of the weight of the dry brick. The absorption expressed in this way is made to depend, not only upon the amount of water absorbed, but also upon the density of the materials composing the brick. The writer has expressed the absorption in two ways - in per cent of the <u>weight</u> of the brick, and in per cent of the <u>volume</u> of the brick. In addition, the specific gravity, or density, of the brick was calculated. The method of making the absorption test was as follows:

After remaining in a steam heated room for at least three weeks the brick were weighed (W_1) and immersed in water. They remained in water 48 hours and were then weighed suspended in water (W_2). They were then placed on a dry surface and allowed to drain for about 15 minutes, after which they were wiped with waste and weighed again (W_3). Then (W_3-W_1) = the weight of the water absorbed.

$(W_3 - W_1)$ = also the volume of the water absorbed if the decimal (gram-centimeter) system is used, which was the case. $\frac{W_3 - W_1}{W_1}$ = weight of water absorbed divided by the weight of the brick dry = absorption as usually expressed.

$W_3 - W_2$ = weight of water displaced by the brick as a whole, including water absorbed = volume of the brick.

$$\frac{W_3 - W_1}{W_3 - W_2} = \frac{\text{volume of water absorbed}}{\text{volume of brick}} = \text{absorption in per cent}$$

of volume.

$$\frac{W_1}{W_3 - W_2} = \text{density of the brick as a whole.}$$

If the density of the materials composing the brick is desired, it equals $\frac{W_1}{W_1 - W_2}$. The results of these tests together with some other results for comparison are given in Table IV.

Freezing Test.—If the effect of freezing is as described above, we would expect it to be indicated by a diminished strength due to the breaking of the bond, and an increased absorption due to the slight pushing apart of the particles. That such an effect does result from the freezing will be seen from Table V.

Two sets of freezing tests have been made. In the first set, half brick were immersed in water 48 hrs.. They were then taken out and placed in a galvanized iron can which was immersed about seven-eighths of its depth in the brine vat of a refrigerating plant. The can was taken out in the morning about 8.00 A. M. and the water at about 50° F. was poured in on the brick. About 4.00 P. M., the water was poured off and the can again immersed in the brine. This was continued until the brick had been frozen 20 times. The average temperature of the brine was 3° F. The absorption was taken and after the brick had been dried they were crushed. Also, the loss

Table IV.

Absorption and Specific Gravity.

Ref. No.	Private Mark	Kind of Brick	Av. Absorption by Weight	Av. Absorption by Volume	Av. Density Material	Av. Density Brick	Number Tested	Authority
1	C.	S-L	10.81	29.03	2.687	1.871	15	Curfman
2	C.S.	"	8.97	23.43	2.613	1.912	3	"
3	U.	"	13.13	24.00	2.397	1.821	18	"
4	S.	"	12.70	22.32	2.265	1.775	22	"
5	A.	"	9.4	18.13	2.360	1.933	3	"
6	T.	"	8.5	15.80	2.214	1.864	5	"
7		Clay	5.98	12.29			9	"
8		"	10.00					Note 1
9		S-L	11.9					" 2
10		"	10.5				3	" 3
11		"	11.4				2	" 4
12		"	12.9				1	" 5
13		"	7.9				3	" 6
14	Gray	"	13.1	30.5	2.51	1.74	10	" 7
15	Yellow	"	13.6	14.6	2.46	2.10	10	" 7
16	M.C.	"		35.9	2.652		5	" 8
17	K.	"		47.3	2.629		5	" "
18	L.	"		31.1	2.65		5	" "

1. Prof. I. O. Baker, "Treatise on Masonry Construction", p.21
2. Colorado School of Mines, in the Clay Worker, Jan., 1905.
3. Pittsburg Testing Labratory, in Trans. Am. Ceramic, Soc. Vol. IV, p. 173.
4. Columbia University, in advertising literature of brick company.
5. Mc Gill University in advertising literature of brick company.
6. U. S. Naval Academy, in advertising literature of brick company.
7. S. V. Peppel, "The Manufacture of Artificial Sand Stone", in Transactions of the American Ceramic Society, Vol. IV.
8. H. B. Fox, University of Illinois, "A Comparative Study of Sand-Lime and Clay Brick", in Clay Record, Jan. 16, 1905.

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in weight due to disintegration or flaking off was determined by taking the difference dry before and after freezing. The other halves of the same brick also were tested for crushing strength. The results appear in Table V.

Table V.

Effect of Freezing on Crushing Strength and Absorption.

Ref. No.	Private Mark	Kind of Brick	Average Crushing Strength (lb. per sq.in.)		Absorption by Weight		No. Tested	Per cent Loss in Weight
			Before Freezing	After Freezing	Before Freezing	After Freezing		
1	C	S-L	4448	3430	10.85	14.25	4	
2	CS	"	6200	6225	8.8	9.2	2	
3	U	"	2470	1778	13.16	14.97	6	14.2
4	S	"	1915	1753	12.27	16.92	6	5.3
5	H	Clay	3900	5125	5.6		2	0
6	K	"	5175	7970	3.5		2	0
7	R	"	6360	8130	8.3		2	0
8	MC	S-L	Lost 18 per cent					2.7
9	K	"	Crumbled					100.0
10	L	"	Lost 8 per cent					13.2

Note- No. 8, 9, and 10 are results by Mr. H. B. Fox in Clay Record for Jan. 16, 1905. The test was about the same as that of the writer. The average of four kinds of clay brick tested by Mr. Fox shows a decrease in strength of 22 per cent, but no loss in weight.

Accounts of other freezing tests have been found, but they do not seem to be of sufficient value to be quoted. Most of them consisted of freezing and thawing a brick once or twice. If the brick came out of the test still looking sound, it was pronounced "satisfactory". The writer wants a more definite statement of results than that they were "satisfactory" to the one making the test. Also, as stated above, the writer believes that one freezing, when the brick is thoroughly soaked with water, is about equivalent to one Illinois winter. Freezing twice, as in the test mentioned above, might prove that the brick might stand two winters. But, before the writer will use the brick, he wants assurance that they will last more than two winters.

It will be noticed in Table V. that brick No.2 even gained slightly in strength, and very slightly in absorption. One of these brick lost 10 per cent of its absorption, and gained 29 per cent in strength after freezing. One could scarcely detect the difference between the frozen half and the one not frozen. It was certainly improved in strength by freezing. The writer has seen some other results where this was the case, and he is inclined to believe that it is due entirely to the quality of the brick. It will be seen that the brick which gave this result were also very good in other respects. It may be that sand-lime brick which are properly made are improved, or at least are not injured, by freezing. It will be noticed that the clay brick gained in strength. The writer was surprised at this result; but, knows of no place in the test where an error of this magnitude might have entered. However, if this was due to something in the method of proceedure, it may be that the same thing increased the strength of the sand-lime brick marked S so that the effect of freezing these brick was greater than appears from the table.

Effect of the Weather. The first test undertaken by the writer was one intended to show the effect of the weather on the brick. The test was not conducted scientifically and the results are of little value; but the method will be described briefly and the error pointed out.

Two each of three kinds of brick were placed in the open air where they were exposed to the sun, wind and rain. They remained there eight months- from August to March inclusive. One of each of these kinds of brick was kept in a closed box in a dry place.

At the end of the eight months the brick which were exposed were removed and placed in a dry room, where they remained for three weeks before being crushed. There had been no rain for several days previous to their removal from the open air. The transverse test and crushing test were made on these brick. The results are shown in Table VI. The average for the two exposed brick are given.

Table VI.

Effect of Weather.

Ref. No.	Private Mark	Modulus of Rupture lb. per sq.in.		Crushing Strength lb.per sq. in.	
		Original	Exposed	Original	Exposed
1	A	1010	518	2420	2345
2	C	506	603	2710	2975
3	CS	857	800	5140	4025

The test does not prove anything conclusive, because different brick were used. If the brick had been broken in halves, and one half exposed and the other half kept as it was for comparison, the results would have been of more value.

<u>Effect of Fire</u>. There are three conditions under which the brick may be subjected to the action of fire. They may be in the walls of a burning building and be subjected to the heat only; or they may be subjected to the heat and while hot be dashed with water; or they may be used in a boiler setting, and be subjected to intense heat for a period lasting from a few hours to several months. The writer has attempted to determine the effect of each of the three conditions on the brick.

To imitate the first condition a little kiln or oven was built of ordinary clay building brick. In this a fire was made of wood. The bricks to be tested were placed on a kind of grating above the fire and the flames made to pass among and around them. This was continued for 25 minutes after which the chimney opening was closed and the brick were allowed to bake for 15 minutes longer. They were then removed and allowed to cool in the open air. It is not known what temperature was reached. (Some clay brick were tested for comparison.) When cool the brick were tested in three ways. They were examined for cracks or checks; they were then rapped sharply several times with a poplar stick about 2" X 2" X 12" as a test for soundness; those that withstood this test were crushed.

Results:- Six sand-lime brick and three clay brick were used in this test. Two of the sand-lime brick showed no cracks, but went to pieces under the blows of the stick. The four others showed cracks, but two of them withstood the blows of the stick. The av - erage crushing strength for these two was 2,510 lb. per sq. in. The two thus surviving were of the kind marked "C" in Table III for which the average crushing strength is 4,344 lb. per sq. in. Of the three clay brick one was badly cracked and pieces came off under the action of the stick. The two others showed no cracks and withstood perfectly the blows from the stick. They were not crushed.

To imitate the second condition mentioned above, the same oven and same method was used as above, and at the end of the baking process water was dashed on the brick while still over the fire.

Results:- Five sand-lime brick and three clay brick were used in making this test. All but one of the sand-lime brick fell apart

being dropped on the solid ground from a height of three feet. The remaining one showed checks but withstood the blows of the stick. It showed a crushing strength of 1,940 lb. per sq. in.as compared with the average 4,344 lb. per sq.in. for that brand of brick. Of the clay brick one was cracked and another checked but both survived the stick. The clay brick was not crushed.

To imitate the third condition, some half brick were placed on the moving grate of a boiler furnace, which took them through the fire in about an hour. When the brick came out they were found to be vitrified to the depth of about $\frac{1}{4}$ inch on the sides which were struck by the current of gases coming through the coals. The side not thus acted upon by the gases was not vitrified. When the brick was broken, the interior was found to be very soft and crumbly, having lost most of its bond.

In a subsequent test, a sand-lime brick and a fire brick were sent through the fire in the same manner as above. The attendant in charge of the boiler, before removing the ashes threw water on them. The fire brick came out whole, but was cracked so that it fell apart from a slight blow of the foot. The sand-lime brick broke into such small pieces that could not be found in the ashes.

Another test was made in which two half brick of the same kind were laid on the bridge wall of a water-tube boiler when there was no fire. The boiler was then fired for about 12 hours and the fire allowed to go out. The brick were removed apparently sound except for a few hair line cracks. They were placed in a room supposedly dry. Four days later they were examined. They had crumbled so that they could not be picked up entire. They had cracked open,

and resembled lumps of quick-lime which had just begun to slake. The writer attempts to explain the action in this manner: Part of the lime in the original brick was in the form of carbonate $CaCO_3$, and the heat of the furnace drove off CO_2, leaving quick-lime, CaO, which drew enough moisture from the air to slake it.

Such conclusive results were obtained from this test that another was made as nearly like it as possible. One of each of six kinds of sand-lime brick was used. The brick were all affected in the same way but to a different extent. The brick of the same kind as used in the preceeding test, marked S in the tables, behaved in exactly the same way as before. The kind marked A developed large cracks but not so bad as S. The effect on the others was in the following order from least to most:- CS, T, U, and C.

Mr. S. V. Peppel in an article entitled "The Manufacture of Artificial Sandstone" in Vol.IV of the Transactions of the American Ceramic Society, gives the results of the two experiments both of which show that intense heat tends to destroy the bond.

Conclusion.

From the results of the tests the writer concludes that the average sand-lime brick as now made has sufficient strength for a face brick and sufficient durability for a very dry climate, or for one where the temperature does not often get below 20° F. They are about the equivalent of the ordinary soft or salmon brick in durability. The effect of the weather on the latter may easily be seen in some old buildings. The writer further concludes that sand-lime brick are made which will stand any climate. The question natur-

ally arises how to distinguish good brick from poor ones. If the writer were called upon to specify the requirements for sand-lime brick for his own use, he would say they should have an average absorption of not more than 9 per cent by weight, with a maximum for any one brick of not more than 11 per cent;and an average crushing strength of not less than 5,500 lb. per sq. in. for a single brick. The writer would further satisfy himself beyond any doubt that the brick had been steamed under a pressure of at least 100 lb., preferably 150 lb. The writer further decides that sand-lime should not be used as a fire brick directly exposed to the flames, but that they would make good insulating brick. The sand-lime brick industry is yet in it's infancy, is imperfect and many of the manufacturers are inexperienced, so that many inferior brick are put upon the market. When the people become better acquainted with the brick and learn to distinguish good from inferior ones, the inferior quality will go out of the market. The writer believes that sand-lime brick are destined to take the place of clay brick above ground in those localities where good sand is easier to get than good clay.

IV. EQUIPMENT OF PLANT AND COST OF MANUFACTURE.

There are various patented processes and machines used in the manufacture of sand-lime brick. There is no patent on the essen - tial part of the process - the hardening by steam under pressure. A few of the most notable of the patented machines will be mention-

ed farther on.

The mechanical equipment of a plant consists esentially of, (1) power and transmission; (2) lime-preparing machinery; (3) mixing apparatus; (4) presses; (5) trucks; and (6) hardening cylinders or"kettles".

The power and transmission is such as is used in an ordinary clay-brick plant. However, the boiler capacity should be greater than that required to furnish power, in order to supply steam for the hardening cylinder.

The lime-preparing machinery is of two kinds. If quick-lime is used, it needs simply to be ground; but if the lime is hydrated before being mixed with the sand, some sort of hydrating apparatus is required. The form which seems to be most economical and efficient is that in which the quick-lime is placed in iron boxes on trucks low enough to run under the brick trucks. Some water is thrown on the lime and allowed to stand a few minutes; the lime boxes are then run into the hardening cylinder under the brick trucks. If too much water has been added to the lime, the excess is evaporated by the heat of the steam in the cylinder. If too little has been added, the steam completes the hydration. This form of apparatus is shown in Fig. 3.

The mixing machinery essentially consists of one or more mixing machines, elevators, conveyors, and a moistening apparatus. Attention is called briefly to one machine because it is entirely different from ordinary mixing machines. The striking feature of this machine is that the mixing takes place in a vacuum chamber

surrounded by a steam jacket. The machine was invented by Mr. Wilhelm Schwartz of Zurich, Switzerland, who claims that it allows complete control of the amount of moisture and the temperature during the mixing. A drawing and complete discription of this apparatus is found in Engineering News, February 19, 1903 p. 179.

Fig. 3 - Showing Arrangement of Track, Trucks, and Cylinder.

The presses now in use are such as are used for the dry pressed clay brick; but they do not usually furnish a pressure of more than 6,000 or 7,000 pounds per sq. in., which, as we have seen, is not

sufficient for sand-lime brick. There is still room for improvement in this direction. Fig. 4 shows one of the presses in common use

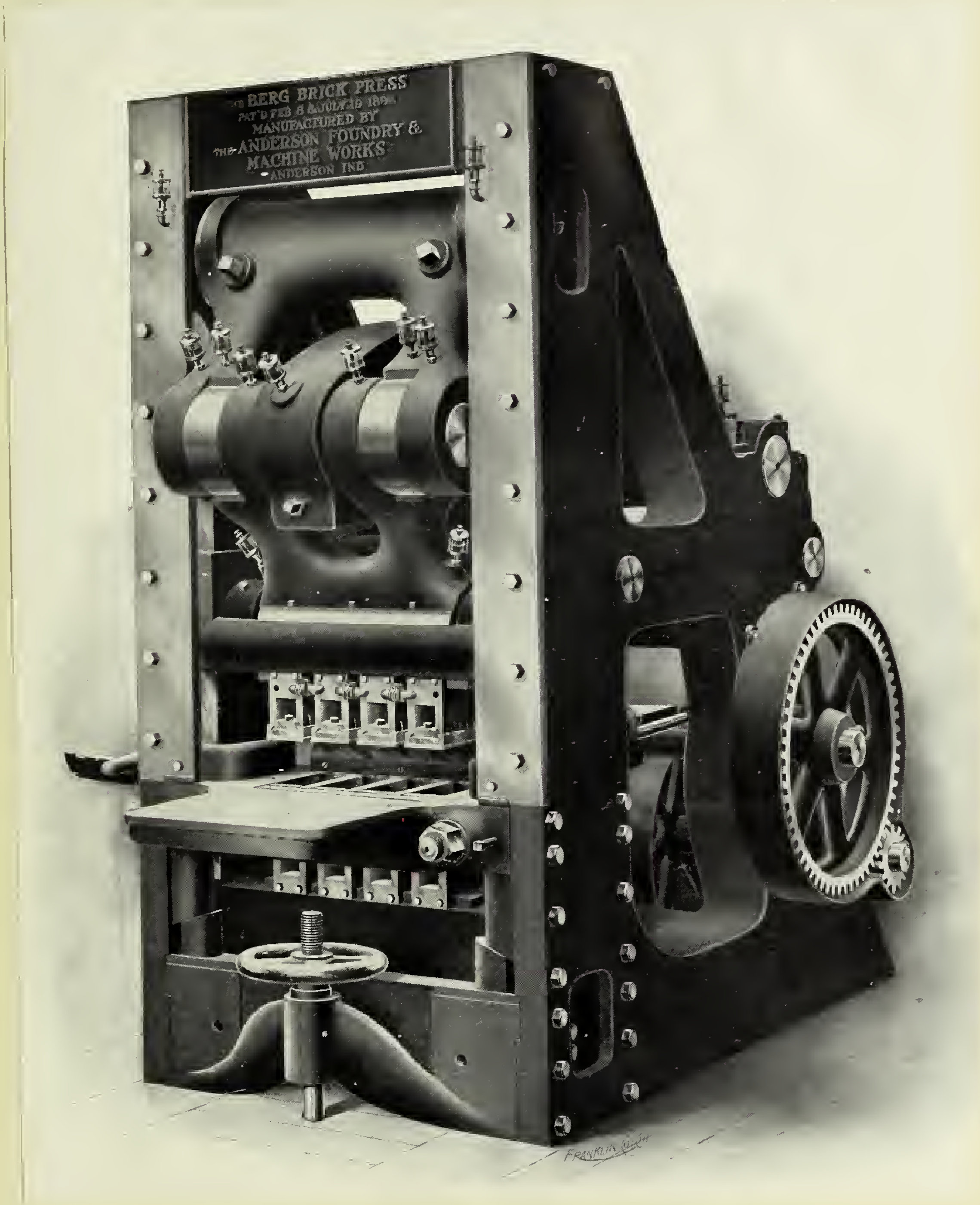

Fig. 4 - A Press Used for Sand-Lime Brick.

The trucks are of steel of the ordinary type, but are perhaps somewhat smaller than usual. They are arranged to be coupled together, and the entire train is run into the hardening cylinder. If the lime truck described above is used, the brick truck must be slightly modified to provide clearance under it for the lime truck. See Fig. 3, page 26.

The hardening cylinder or "kettle" is much like the shell of a large boiler. This cylinder is made of boiler plate $\frac{5}{8}$ to $\frac{3}{4}$ inch thick, and varies in size from $5\frac{1}{2}$ to 7 feet in diameter, and from 35 to 67 feet in length, according to the capacity of the plant.

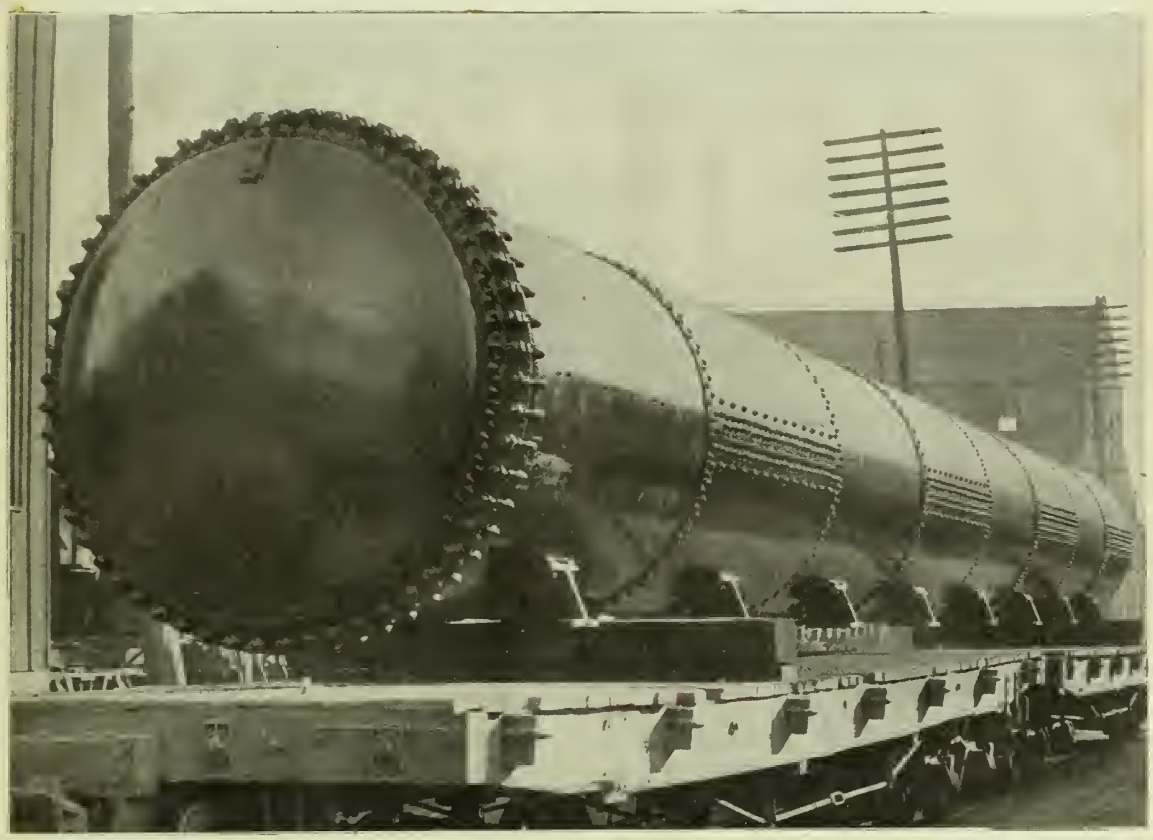

Fig.5-The Hardening Cylinder. Showing head hinged at top and fastened with bolts.

The head of the cylinder is usually fastened on with $1\frac{1}{4}$" or $1\frac{1}{2}$" bolts so arranged that the fastening or removing away may be readily accomplished. The fastening of this head is an important item, since a failure here might cause serious loss of life or damage to the plant. There are usually two or more of these cylinders so that one may be open and filling, while the other is closed and steaming. It has occured to the writer that since the blowing off of one cylinder and the raising of the pressure in the other must take place at nearly the same time, there would be great economy in passing the steam from the hot cylinder to the cold one till the pressure was equalized. The writer is not sure this has ever been done. To prevent waste of steam the cylinder should be insulated in some way. Perhaps the best way is to brick it up with sand-lime brick, since they are very poor conductors of heat.

Fig. 6 - A Sand-Lime Brick Plant.

The cost of a plant erected and fully equiped for the manufacture of 20,000 bricks per day is about $25,000. This includes only one hardening cylinder, which does not afford the strictest economy, but may be sufficient for a plant just starting.

Fig. 7.- Showing Newly Made Brick on Cars, Just Pulled Out From the Cylinder.

The cost of making the bricks varies greatly for different localities. The following are the items of expense connected with a plant having a capacity of 20,000 bricks daily:

1 Engineer	$2.50
1 Fireman	1.75
8 Laborers	14.00
5 Tons Coal	12.50
$2\frac{1}{2}$ Tons Lime	12.00
Oil	1.00
Chemicals	1.00
Wear and Tear	3.00
Interest on Cost of Plant	4.00
Total	$51.75
Cost per M	$2.58

This estimate is based on the supposition that the sand is in the immediate vicinity and costs nothing but the labor of handling. It will be noticed that there is an item of $1.00 for chemicals. This is for the "Huennekes System". The above includes nothing for washing or grinding the sand. Everything in this estimate is very low. Manufacturers estimate the cost variously at from $3.00 to $5.00 per thousand. However, it is very probable that a plant favorably situated in regard to sand, lime, and coal could make brick for $3.00 per thousand.

Any one who might wish further details in regard to processes or machinery is referred to the following patents issued in the United States;-

No.	470333, Mar.8, 1892	granted	to	Charles George.
"	591168, Oct.5, 1897	"	"	Christian Heingerling.
"	624900, May 16, 1899	"	"	Thomas Barber.
"	661443, Nov.6, 1900	"	"	Emery Coulon.
"	663904, Dec.18, 1900	"	"	Peter Kleber.
"	670299, Mar.19, 1901	"	"	Wilhelm Schwartz.
"	681580, Aug.27, 1901	"	"	Carl Rensing.
"	683337, Sept.24, 1901	"	"	Walter Schultliess.
"	684649, Oct.15, 1901.	"	"	Wilhelm Olschewskey.
"	685094, Oct.22, 1901.	"	"	Iven Edmund Boirie.
"	686333, Nov.12, 1901	"	"	Paul Joseph Prior.
"	693906, Feb.25, 1902	"	"	Edward Rott.
"	697391, Apr.8, 1902	"	"	Herman Elisha Brown.
"	702611, June 17, 1902,	"	"	Oscar Hugo Anderson.
"	707898, Aug.26, 1902	"	"	Teodor Boas.